

SYSTEM FOR COLLECTING DATA USED BY SURFACE PROFILING SCHEME

Cross-reference to Related Patent Applications

5 This patent application is co-pending with one related patent application entitled "MOVABLE PLATFORM FOR USE WITH SURFACE PROFILING SYSTEM", filed on the same day and by the same inventor as this patent application.

10 Field of the Invention

 The invention relates generally to surface profiling systems, and more particularly to a system for collecting data measurements that are used by a surface profiling processing scheme.

15 Background of the Invention

 Rolling surface profiling apparatus have been used for some time to measure the profile or contour of a material surface, floor, road, etc. For example, U.S. Patent No. 20 3,056,209 issued to Robert E. Oliver on Oct. 2, 1962, discloses a three-wheel, continuous recording, analog computation device that endeavors to accurately measure the contours of a surface with respect to a reference plane by the use of a "floating" center wheel which produces a vertical 25 displacement signal with respect to the distance traveled over the surface by a double integration procedure. Equations 1

through 4 in the Oliver patent describe the geometrical and mathematical relationships between the measured and desired quantities that make such a device theoretically possible. However, the reference notes that it is necessary to consider stability problems and proceeds to change the ideal coefficients given in Equation 4 to certain values which the patentee found, through experience, to yield satisfactory results. The patentee justifies the abandonment of the ideal mathematical model as necessary to overcome serious problems of noise compounding that is inherent in all such integration devices.

A three-wheel rolling digital surface measurement apparatus is disclosed by Allen Face in U.S. Patent No. 5,535,143. Similar to the Oliver patent, three collinear, sequentially oriented, regularly spaced and approximately equi-diameter wheels are provided on one side of a measurement platform. The middle wheel is a floating wheel having a linear position transducer coupled thereto. The rear wheel has an odometer coupled thereto. On-center spacing between each adjacent pair of wheels is given as S .

More specifically, the device of U.S. Patent No. 5,535,143, illustrated schematically in FIG. 1, includes a rigid frame 2 rotatably supporting a rear wheel 3 and a front wheel 4 that are co-linear and separated by the distance $2S$. Support wheels 3 and 4 contact the measured surface 1 at points i and $i-2$, respectively. Midway between support wheels

3 and 4, a sensing wheel 5 is in contact with surface 1 at point i-1. Sensing wheel 5 supports an axially movable column 6 that is connected to frame 2 in such a manner that its movement relative to frame 2 is restricted to an axis normal to the line joining the centers of wheels 3 and 4. A linear position transducer 7 having an output signal R is mounted on frame 2 in such a manner that its electrical output is directly proportional to the position of column 6 relative to frame 2. An odometer 8 is mounted on frame 2 to produce an electrical signal D that is directly proportional to the distance traveled by rear wheel 3 across surface 1. The linear position transducer signal R and odometer signal D are both input to a digital computer 9 which is programmed to interpret the two signals and record the instantaneous position, in convenient dimensions, of column 6 relative to frame 2 every time rear wheel 3 travels the distance S across surface 1. All of the above named individual components, as well as the electrical powering apparatus (not shown) required for the apparatus, are commercially available items. Similarly configured surface curvature measurement devices have long been known to those skilled in the art.

In accordance with the teachings of U.S. Patent No. 5,535,143, each wheel contacts the measured surface at that point where the tangent to the wheel and the tangent to the surface coincide. Due to the undulation of the measured surface, the line connecting the center of each wheel and its

associated contact point will rarely be perpendicular to the elevation datum. While the computer of this invention assumes that every reading point will fall on a normal from the wheel center to the elevation datum, in actuality, most of the reading points will be slightly displaced from the assumed position owing to the wheel surface contact geometry.

The computer of this invention records the column position transducer signal at the instant the odometer indicates that the rear wheel has traveled the distance S . However, between successive reading points, the rear wheel is not traveling in a straight line, but along an undulating surface. Thus, while the computer assumes that the horizontal displacement between successive readings is the constant distance S , in actuality the straight line distance between each successive reading will vary slightly according to the length of the undulating surface profile over which the real wheel travels. Thus, odometer triggering results in a slightly variable reading point spacing as the sensor wheel and front wheel contact points at one reading position will rarely coincide exactly with the rear wheel and sensor wheel contact points at the next reading position.

"Curvature" readings in both of the above-described surface profiling systems/schemes (as well as other similar prior art surface profiling schemes) are subject to measurement errors. Furthermore, the "curvature" readings must be double integrated in order to obtain the desired

elevation profile of the surface. However, the nature of the double integration process causes any attendant measurement errors to be amplified in direct proportion to the square of the distance traveled. This inherent error squaring aggregates quickly and overwhelms the elevation calculation even when individual measurement errors are minute.

Summary of the Invention

Accordingly, it is an object of the present invention to provide a system that can collect data for use by a surface profiling scheme.

Another object of the present invention to provide a system that collects data for use by a surface profiling scheme where the data collected can be used to reduce errors in the surface profiling scheme's calculations.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a system is provided for the collection of measurements for use by a surface profiling processing scheme. A movable platform has first means mounted thereon for generating a measurement of inclination of a surface where the movable platform is positioned and stationary thereon. Second means are mounted to the movable platform for generating measurements of curvature of the surface as the movable platform traverses the

surface. Third means are provided for monitoring distance that the movable platform traverses during a measurement run on the surface. A measurement run is defined by starting and stopping positions on the surface that are spaced apart from one another. A signal is generated by the third means each time the movable platform traverses a predetermined amount of distance during a measurement run. The signal so-generated serves as an indication to stop the movable platform during the measurement run. Fourth means, coupled to the first and second means, collect (i) measurements of curvature while the movable platform traverses the surface during the measurement run, and (ii) measurement of inclination at the starting position, stopping position, and each time the movable platform is stopped during the measurement run.

Brief Description of the Drawings

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein corresponding reference characters indicate corresponding parts throughout the several views of the drawings and wherein:

FIG. 1 is a schematic view of a prior art rolling digital surface profiling apparatus;

FIG. 2 is a schematic plan view of a system for collecting data in accordance with an embodiment of the

present invention where the data collected can be used by a surface profiling scheme;

FIG. 3 is a schematic plan view of the underside of a movable platform illustrating one embodiment of its support system;

FIG. 4 is a schematic plan view of the underside of the movable platform illustrating another embodiment of its support system;

FIG. 5 is a schematic plan view of the underside of the movable platform illustrating still another embodiment of its support system;

FIG. 6 is a schematic plan view of the underside of the movable platform illustrating yet another embodiment of its support system;

FIG. 7 is a schematic plan view of the underside of the movable platform illustrating yet another embodiment of its support system;

FIG. 8 is an isolated side view of a slide used for the center one of the co-linearly aligned supports illustrated schematically in FIG. 4; and

FIG. 9 is a schematic side view an embodiment of the present invention using the movable platform support system illustrated in FIG. 7.

Detailed Description of the Invention

Referring now to the drawings, and more particularly to

FIG. 2, a plan view of a system for collecting data in accordance with the present invention is referenced generally by numeral 100. System 100 is positioned on a surface 102 (e.g., floor, road, or other surface that is to have its surface contour profiled). The data collected by system 100 can be used by a surface profiling scheme that will typically be incorporated into a processor (not shown) which is coupled to system 100 (e.g., hardwired, wirelessly coupled, etc.) to facilitate data transfer therebetween. As will be understood by one of ordinary skill in the art of surface profiling, system 100 can be used by a variety of surface profiling schemes and is, therefore, not limited by the choice of such scheme. For example, either of the afore-described surface profiling schemes disclosed in U.S. Patent Nos. 3,056,209 and 5,535,143 could utilize data collected by system 100 to reduce the errors inherent in these schemes. It is to be further understood that system 100 can supply data for any profiling scheme used to generate "F-numbers" in accordance with the methods set forth by the American Society for Testing and Materials (ASTM) in ASTM E-1155.

System 100 includes a movable platform 110 having a support system (not illustrated in FIG. 2) coupled to the underside thereof for supporting itself and the remaining components of system 100 on a surface 102. Movable platform 110 supports a static inclination measurement device 120, a dynamic curvature measurement device 130, a data collector 140

coupled to each of devices 120 and 130, a distance monitor 150, and one or more signaling devices 160 coupled to distance monitor.

Static inclination measurement device 120 is any device or system that can measure the slope or inclination of surface 102 as an indication of surface elevation changes where movable platform 110 resides when movable platform 110 is stationary. For example, static inclination measurement device 120 could be a simple capacitance or electro-mechanical inclinometer, both of which are well known in the art. Such inclinometers have an axis of sensitivity that should be aligned with what will be the direction of travel of movable platform 110 which, in FIG. 2, is represented by arrow 104.

Dynamic curvature measurement device 130 is any device or system that can take measurements indicative of the changing contour/curvature of surface 102 as movable platform 110 traverses surface 102 along direction of travel 104. This can be done in an analog fashion as disclosed in U.S. Patent No. 3,056,209, or in a digital fashion as disclosed in U.S. Patent No. 5,535,143. Details of a digital version of dynamic curvature measurement device 130 will be provided later below.

Data collector 140 is any device or system that can "collect" data samples from each of devices 120 and 130 at the appropriate times. That is, once activated, data collector 140 collects measurement data from device 120 when movable platform 110 is stationary and collects measurement data from

device 130 when movable platform 110 traverses surface 102. Realization of data collector 140 can be achieved in a variety of ways as would be well understood by one of ordinary skill in the art. For example, data collector 140 could comprise a processor 142 and memory 144 where processor 142 controls data collection and memory 144 provides for the storage of the data. Note that processor 142 could also have a surface profiling scheme programmed therein for processing the measurement data to develop/calculate surface profile measurements of surface 102. The surface profile measurements can be stored in memory 144 for later output.

Data collector 140 could also include an encryption generator 146 for generating an encrypted form of the surface profile measurements generated by processor 142. In this way, both plain text and encrypted versions of the surface profile measurements can be provided with the encrypted version (once it is decrypted) serving as a means to verify the authenticity of the plain text surface profile measurements. Some or all of the surface profile measurements can be encrypted in accordance with ways well understood in the art of cryptography. Accordingly, the type of encryption used is not a limitation of the present invention.

Distance monitor 150 is any device or system that, once activated, can (i) track or monitor the lineal distance that movable platform 110 travels on surface 102 along direction travel 104, and (ii) generate a signal each time movable

platform 110 traverses some predetermined amount of distance. The predetermined amount of distance Δx can be preprogrammed or could be provided as a user input. A variety of mechanical and/or electrical types of devices/systems can be used to accomplish these functions. For example, as will be explained further below, if movable platform 110 is supported by at least one wheel (not shown) contacting surface 102, an odometer can be coupled to the wheel with the odometer's output being monitored by a processor. Note that the processor used to accomplish this function could be the same one forming part of data collector 140.

The signal generated by distance monitor 150 is input to signaling device(s) 160 which produces one or more of a visual, audible and tactile alarm each time the signal is generated by monitor 150. That is, one or more alarms are generated each time movable platform 110 travels a predetermined distance following the activation of distance monitor 150. A visual alarm could be realized by one or more lights that are turned on, flashed on/off, etc. An audible alarm can be realized by a buzzer, beeper, synthetic voice etc. A tactile alarm can be realized by a vibrating device worn or held by a user of system 100.

Use of system 100 will now be explained with continued reference to FIG. 2. When surface 102 is to be profiled, system 100 is placed thereon at a position that will define the starting position of a particular measurement run. In the

illustrated example, the starting position is designated by dashed line 200. When a measurement run is to begin, the user activates the various elements of system 100 which are initialized to a start-up state. With system 100 stationary at starting position 200, static inclination measurement device 120 measures the inclination of surface 120 at that location along what will be direction of travel 104. Measurement of inclination occurs along direction of travel 104 because the axis of sensitivity of device 120 was aligned with the moving direction of movable platform 110.

To insure that device 120 has a sufficient amount of time to get an accurate reading of surface inclination, data collector 140 can incorporate a timing function that triggers signaling device(s) 160 to indicate to a user that movable platform 110 can be moved. Such a timing function could be re-started each time system 100 is stopped during a measurement run as will be explained below.

After the static inclination measurement is taken at position 200, a user moves (e.g., pulls) movable platform 110 on surface 102. As platform 110 traverses surface 102, data collector 140 collects equi-spaced curvature measurements taken by dynamic curvature measurement device 130. When distance monitor 150 determines that predetermined distance Δx has been traveled along direction of travel 104, a signal is generated by distance monitor 150 and passed to signaling device(s) 160. The visual, audible and/or tactile alarms

produced by signaling device(s) 160 serve as an indication to the user to stop movable platform 110 at an interim static measurement position 202. Once system 100 is stopped, data collector 140 again collects a static surface inclination measurement from device 120. Each time system 100 is stopped, the two most recent static inclination measurements are used to correct the inherent errors associated with the double integration of the dynamic curvature measurements collected over the most-recently traveled distance Δx .

After the static inclination measurement is complete (e.g., as indicated by signaling device(s) 160), system 100 is moved again along direction of travel 104. As system 100 moves, dynamic curvature measurements are again collected by data collector 140. When platform 110 has once again traveled the distance Δx , distance monitor 150/signaling device(s) 160 cooperate to produce another indication for the user to stop movable platform 110 for a static inclination measurement. System 100 is operated in this fashion for the entirety of a desired measurement run which terminates at a selected stopping position 204. After the last static inclination measurement is collected at stopping position 204, system 100 is deactivated to terminate the measurement run. The collected data measurements can be processed by an on-board or remote surface profiling scheme known in the art.

As mentioned above, system 100 can be realized in a variety of ways. For example, a variety of embodiments of

movable platform 110 are illustrated from the underside thereof schematically in FIGs. 3-7. In FIG. 3, movable platform 110 has a frame 12 supported by a plurality of support wheels to include at least four wheels 14, 16, 18 and 20, each of which is indicated by a "W". Wheels 14, 16 and 18 are three co-linearly arranged wheels with wheel 16 centered between wheels 14 and 18 and separated from each of wheels 14 and 18 by a distance S. Wheels 14, 16 and 18 are aligned rotationally to define the above-described linear direction of travel 104 when movable platform 110 is moved on a surface. Center wheel 16 is further configured to move vertically (i.e., into and out of the page for the view illustrated in FIG. 3) or substantially vertically in coincidence with the contour of the surface on which movable platform 110 rests. For example, wheel 16 could be coupled to frame 12 using an axially movable column or piston (not shown) with a linear position transducer coupled thereto as used in U.S. Patent No. 5,535,143, the contents of which are hereby incorporated by reference. Wheels 14 and 18 are constrained from such vertical movement.

Spaced apart from co-linearly arranged wheels 14, 16 and 18 is at least one wheel 20 which is also aligned for rotation that is coincident with direction of travel 104. Wheel 20 is provided to balance movable platform 110. Wheel 20 could also be replaced or supplemented with additional wheels such as wheels 22 and 24 illustrated in phantom. Each of the above-

described wheels is rigid and typically has a solid rubber tire mounted thereon for contacting a surface.

To eliminate errors associated with wheel size differences, wheels 14, 16 and 18 can be coupled to one another such that their rotational movement is synchronized. That is, one full rotation of wheel 14 translates into one full rotation of each of wheels 16 and 18 irrespective of any size differences between the wheels. Such synchronized rotational movement is illustrated schematically by an endless loop 30 coupled to each of wheels 14, 16 and 18. In implementation, such synchronization can be realized in a variety of ways (e.g., geared wheels with a chain coupling the gears, wheels belted together, etc.) as described in the afore-referenced co-pending patent application.

Movable platform 110 is not limited to the use of three co-linearly aligned wheels 14, 16 and 18. For example, in each of FIGs. 4-6, one of the co-linearly aligned wheels is replaced with a support "S" that slides on the surface on which the movable platform rests. For example, in FIG. 4, center wheel 16 (FIG. 3) has been replaced with a slide 56 that slides on the surface as wheels 14 and 18 are rolled thereover. In this case, only wheels 14 and 18 are synchronized by endless loop 30. By way of example, slide 56 can be realized as illustrated in FIG. 8 where a semi-circularly shaped slide 56 is coupled to frame 12 by a piston 132 that allows slide 56 to move vertically in coincidence

with the contour of surface 102. A linear position transducer 134 can be coupled to frame 12 for measuring vertical movement of slide 56 via the vertical movement of piston 132. The surface of slide 56 contacting surface 102 should present a durable low-friction interface. Examples of suitable materials include ceramics, carbides, etc. In FIGs. 5 and 6, wheels 14 and 18 are replaced with slides 54 and 58, respectively, with synchronization of the remaining two of the co-linearly aligned supports being indicated by endless loop 30. Construction of slides 54 and 58 can be similar to that of slide 56.

Another embodiment of a support system for movable platform 110 is illustrated in FIG. 7 where wheels 14 and 16 are replaced with slides 54 and 56, respectively, thereby leaving only one wheel 18 in the co-linear arrangement of supports. This embodiment eliminates the errors associated with wheel size differences without requiring apparatus for the above-described wheel synchronization.

Regardless of the embodiment of movable platform 110, measurement devices 120 and 130, data collector 140, distance monitor 150, and signaling device(s) 160 will be supported thereon. By way of example, one embodiment of system 100 is illustrated in FIG. 9 which is based on the movable platform construction illustrated in FIG. 7. Movement of frame 12 is facilitated by a leash 170 that is coupled thereto and used to pull frame 12 on surface 102. An inclinometer 122 is mounted

on frame 12 with its axis of sensitivity aligned parallel to the line defined by the co-linear arrangement of slides 54/56 and wheel 18. Inclinator 122 is coupled to a processor 142 of data collector 140 as described above.

5 Measurement device 130 utilizes linear position transducer 134 to read the vertical position of piston 132 to provide a measurement of vertical movement of slide 56. These vertical positions are collected by processor 142 as frame 12 traverses surface 102. The static and dynamic measurements
10 collected by processor 142 can be stored in memory 144. As described above, the static and dynamic measurements can also be processed by processor 142 in accordance with a surface profiling scheme with the processed results being made
15 available in a plain text version. An encrypted version of the processed results can also be made available by encryption generator 146.

 An odometer 152 is coupled to wheel 18 to measure distance traveled for each rotation thereof. Odometer 152 will produce a signal at each rotation of wheel 18 that is
20 essentially indicative of the distance traveled by wheel 18 across surface 102. A processor 154 (which could be incorporated with processor 142) coupled to odometer 152 is programmed with the afore-described predetermined distance Δx and the number of revolutions of wheel 18 required to equal
25 Δx . Each time Δx is traversed by movable platform 110, a signal indicative of this fact is supplied to signaling

device(s) 160 where one or more of a visual alarm device 162, an audible alarm device 164, and a tactile alarm device 166 are activated. Upon recognizing activation of one of these alarm devices, the user knows to stop movement of frame 12 so that a static inclination measurement by inclinometer 122 can be collected by data collector 140.

The advantages of the present invention are numerous. The system provides the means to collect surface profiling data measurements that can be used to reduce the inherent errors associated with surface profiling schemes.

Although the invention has been described relative to a specific embodiment thereof, there are numerous variations and modifications that will be readily apparent to those skilled in the art in light of the above teachings. It is therefore to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described.

What is claimed as new and desired to be secured by Letters Patent of the United States is: